Dark matter search perspectives with GAMMA-400 and CALET

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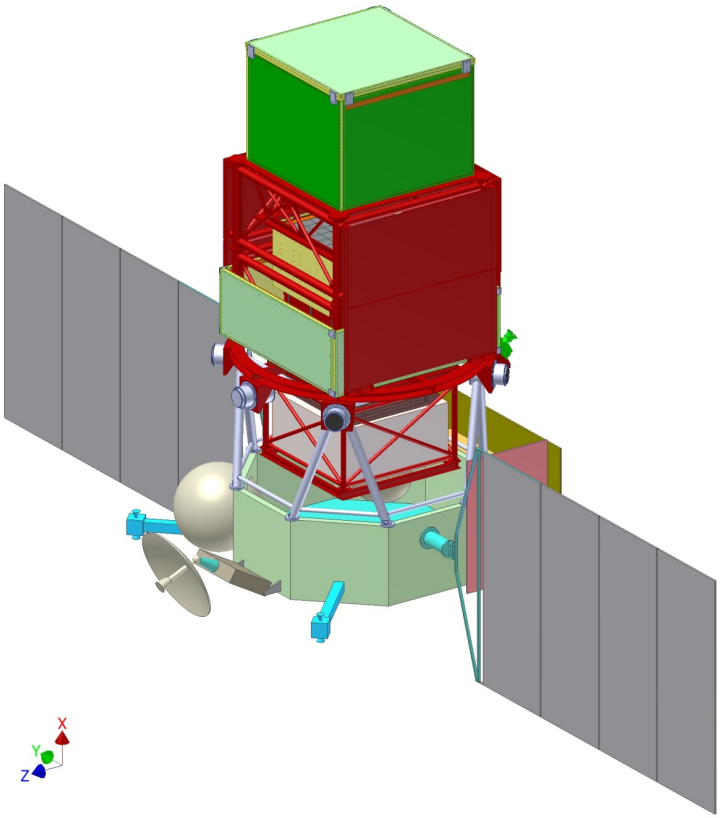
What is GAMMA-400?

- ✓ **GAMMA-400 goals:** follow and deepen the findings of Fermi LAT (similar energy range and instrument overall capabilities)
- ✓ Very suitable for the search for WIMPs. Enhanced performance at high energy (> 10 GeV): PSF and energy resolution
- ✓ **Search for dark matter is the main goal for GAMMA-400 set by V. Ginzburg in mid-1980s**



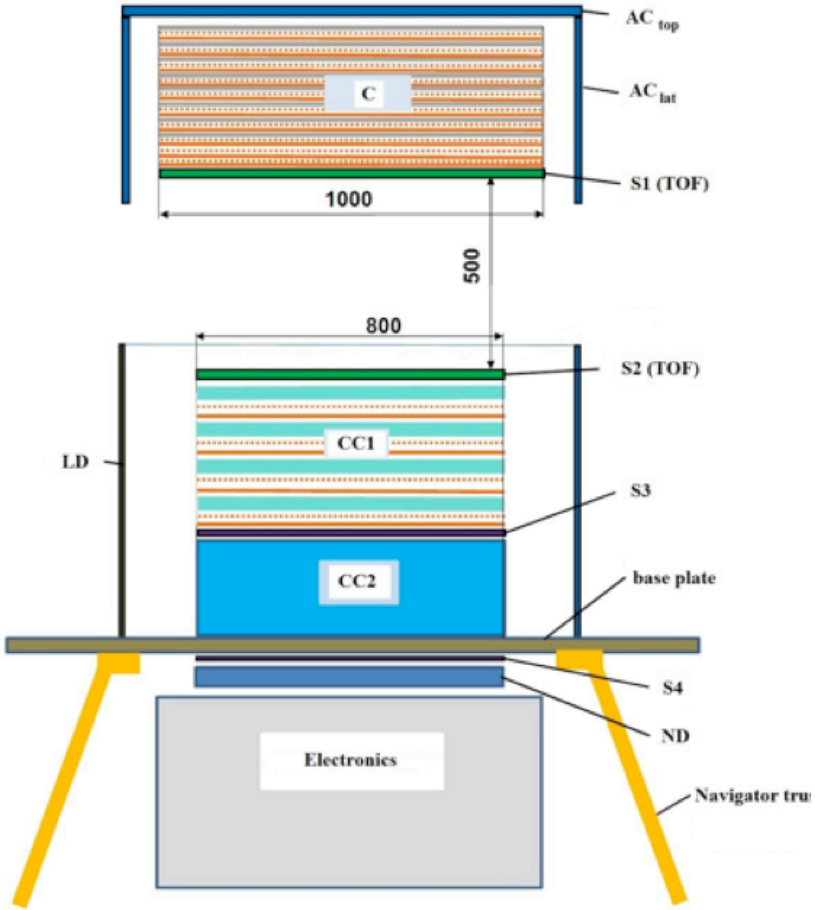
- **A new high-energy space *γ*-ray telescope**
- **Approved and fully funded by Russian Space Agency Russian, included in Federal Space Program**
- **Uses the Navigator service module made by Lavochkin Association, recently used for the RadioAstron mission, planned for other missions**
- **Uses technology similar to Fermi Large Area Telescope (tracker/converter, energy measurement system, anticoincidence detector)**
- **Launch is planned for 2018-2019**

Overview of GAMMA-400 Science Goals

- **Main topics**
  - **Nature of Dark Matter**
  - **The origin of cosmic rays**
- **Extend high-energy *γ*-ray observations after the end of the Fermi LAT mission for multiwavelength analysis in synergy with:**
  - **Radio, optical, X-ray and TeV *γ*-ray observations (CTA)**
  - **Neutrino observations (IceCube, KM3NeT)**
  - **Gravitational radiation observations (ALIGO)**
- **Focus on high-energy gamma-ray tasks which GAMMA-400 will perform better than Fermi-LAT due to its better energy and angular resolution**
  - **Source localization and identification (puzzle of non-ID Fermi LAT sources)**
  - **Discovery of new sources in crowded regions (e.g. Galactic Center, Cygnus)**
  - **Study of spectral structure of diffuse radiation (addresses Dark Matter)**
  - **Study of gamma radiation from Supernova Remnants at low energy (addresses origin of cosmic rays)**

Currently no space-borne high-energy *γ*-ray observations are planned after Fermi LAT observations end (~ 2018)

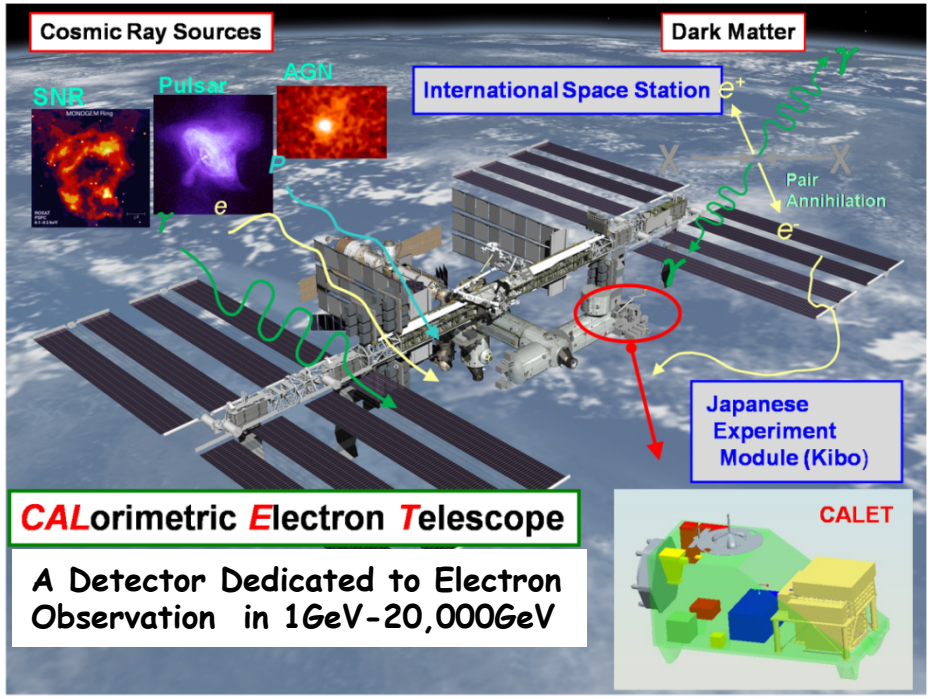
GAMMA-400 Concept



Energy range	100 MeV – 3000 GeV
Field-of-view, sr (E > 1 GeV)	~1.2
Effective area, cm^2 (E > 1 GeV)	~4,000 (~6,000)
Energy resolution (E > 10 GeV)	~1%
Angular Resolution (E >100 GeV)	~0.01°
Converter-tracker thickness	~ $1X_0$
Calorimeter thickness	~ 25 X_0
Proton rejection factor	~ 10^6
Telemetry downlink volume, GB/ day	100
Total mass, kg	2,600
Maximum dimensions, m	2.0 x 2.0 x 3.0
Power consumption, W	2,000

Calorimetric Electron Telescope: CALET

CALET (CALrimetric Electron Telescope) is an astrophysics mission for the International Space Station（ISS) that will search for signatures of Dark Mater and provide the highest energy direct measurements of the cosmic ray electron spectrum in order to observe discrete sources of high energy particle acceleration in our local region of the Galaxy.

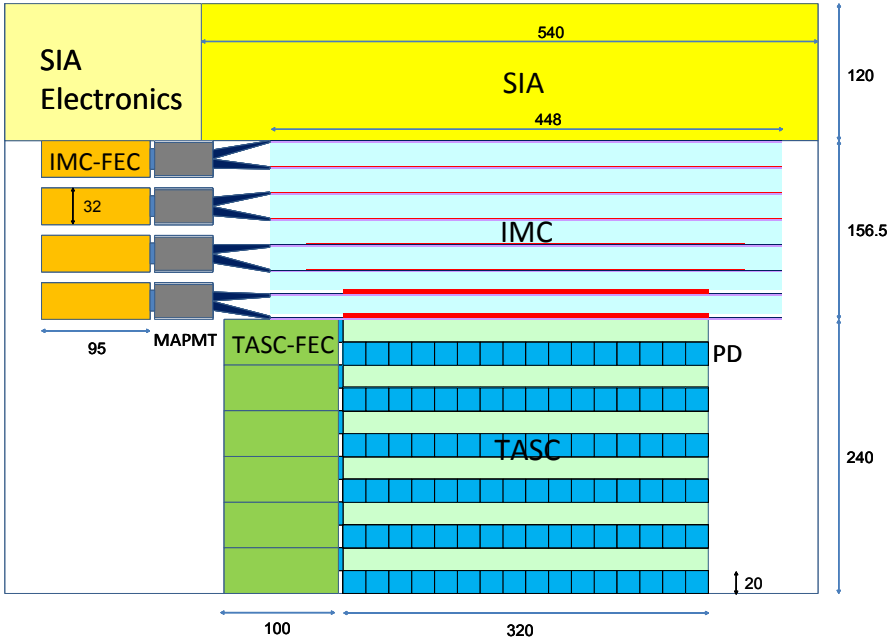


Science Objectives	Observation Targets
Nearby Cosmic-ray Sources	Electron spectrum in trans-TeV region
Dark Matter	Signatures in electron/gamma energy spectra in 10 GeV – 10 TeV region
Origin and Acceleration of Cosmic Rays	p-Fe over several tens of GeV, Ultra Heavy Ions
Cosmic –ray Propagation in the Galaxy	B/C ratio up to several TeV /n
Solar Physics	Electron flux below 10 GeV
Gamma-ray Transients	Gamma-rays and X-rays in 3 keV – 30 MeV

CALET Overview

Observations

- **Electrons** : 1 GeV -10,000 GeV
- **Gamma-rays** : 10 GeV -10,000 GeV (GRB > 1 GeV)
  + Gamma-ray Bursts : 7 keV-20 MeV
- **Protons, Heavy Nuclei**: several 10 GeV- 1000TeV (per particle)
- **Solar Particles and Modulated Particles in Solar System**: 1 GeV-10 GeV (Electrons)



S. Torii, COSPAR 2010

Instrument

- Imaging Calorimeter (Particle ID, Direction)

Total Thickness of Tungsten (W) : 3 X_0

Layer Number of Scifi Belts : 8 Layers ×2(X,Y)

- Total Absorption Calorimeter (Energy Measurement, Particle ID)

PWO 20mmx20mmx320mm

Total Depth of PWO : 27 X_0 (24cm)

- Silicon Pixel Array (by Italy) (or a substitute) (Charge Measurement in Z=1-35)

Silicon Pixel 11.25mmx11.25mmx0.5mm

2 Layers with a coverage of 54 x54 cm^2

CALET Collaboration

Organization: 26 institutions with 94 members, supported by JAXA, ASI, NASA, INFN

JAPAN
Waseda University
JAXA/Space Environment Utilization Center
JAXA/ Institute of Aerospace and Astronautical Sciences
Kanagawa University,
Aoyama Gakuin University
Shibaura Institute of Technology
Institute for Cosmic Ray Research , University of Tokyo
Yokohama National University
Hirosaki University
Tokyo Technology Inst.
National Inst. of Radiological Sciences
High Energy Accelerator Research Organization (KEK)
Kanagawa University of Human Services
Saitama University
Shinshu University
Nihon University
Ritsumeikan University

ITALY
University of Siena
University of Florence & IFAC (CNR)
University of Pisa
University of Roma Tor Vergata
University of Padova

USA
NASA/GSFC
Louisiana State University
Washington University in St Louis
University of Denver

Comparison of instrument parameters for gamma-ray observations

	Space-based instruments				Ground-based instruments		
	Fermi LAT	AMS-2	GAMMA-400	CALET	H.E.S.S. - II	MAGIC	CTA
Energy range, GeV	0.02-300	10-1000	0.1-3,000	10-10,000	>30	>50	>20
Field-of-view, sr	2.4	0.4	1.2		0.01	0.01	0.1
Effective area, m^2	0.8	0.2	~0.4	~0.1	10^5	10^5	10^6
Angular resolution (E>100 GeV)	0.2°	1.0°	~0.01°	0.1°	0.07°	0.05°	0.06°
Energy resolution (E>100 GeV)	10%	2%	~1%	2%	15%	15%	10%

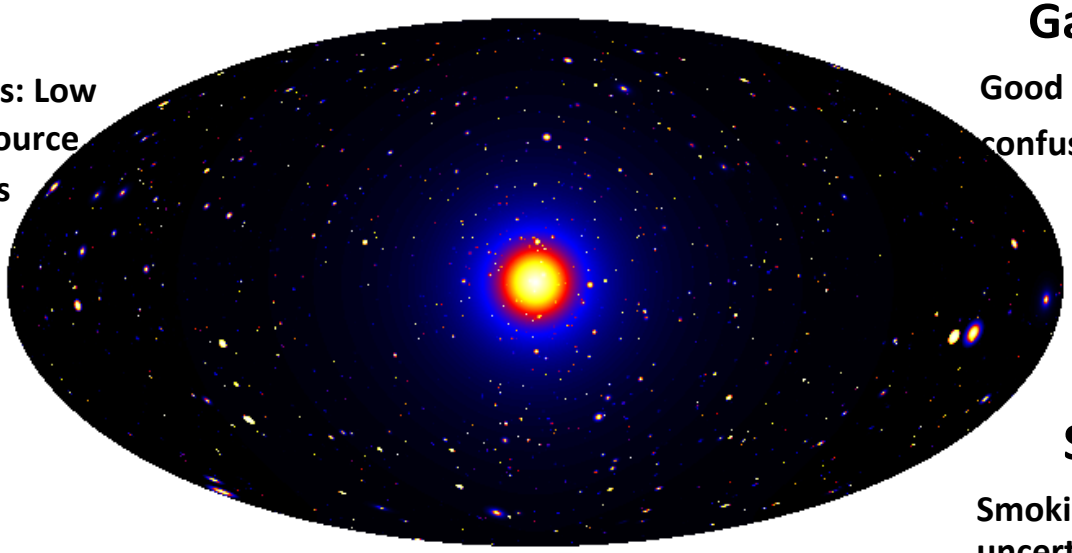
Dark Matter predicted in γ-ray sky

Satellites

Non-Id sources and dSphs: Low background and good source id, but low statistics

Galactic Center

Good Statistics, but source confusion/diffuse background

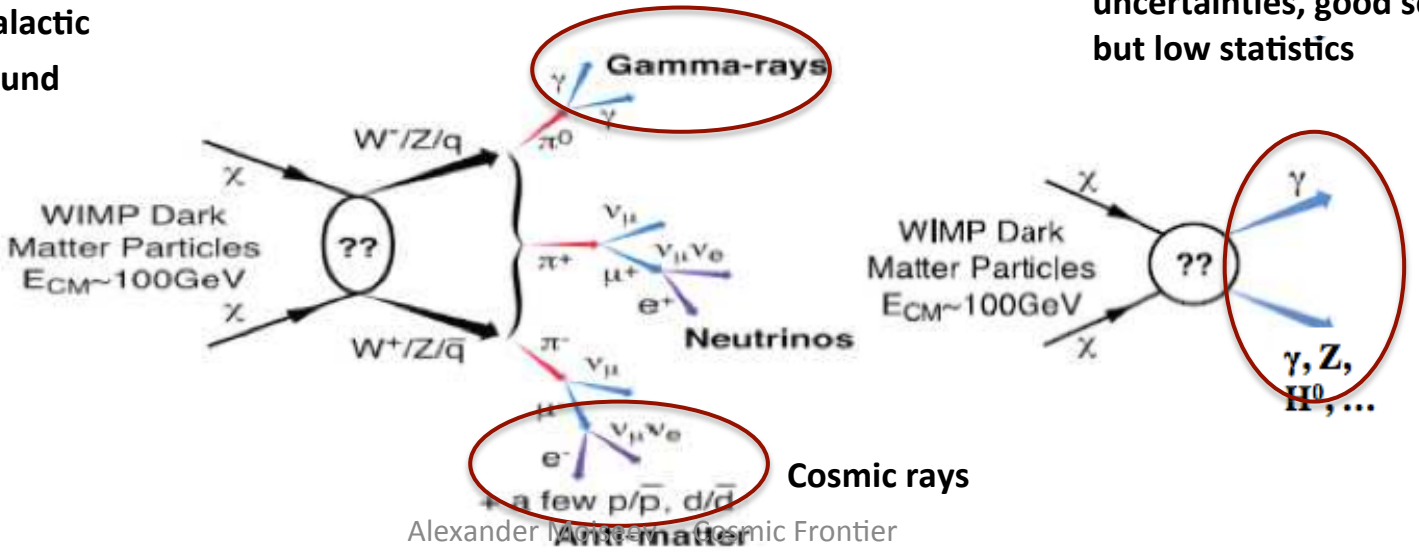


Isotropic contributions

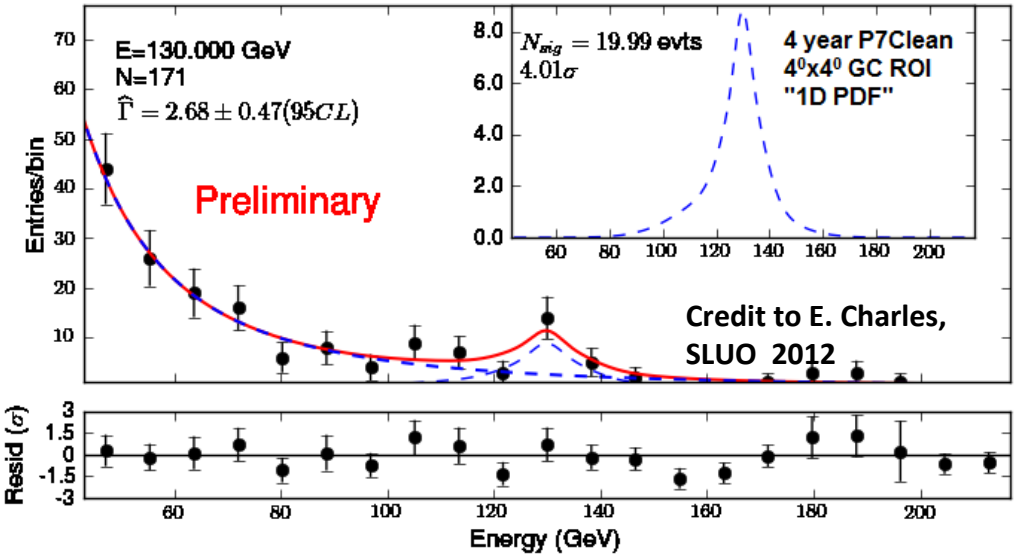
Large statistics, but astrophysics, galactic diffuse background

Spectral Lines

Smoking gun: no astrophysical uncertainties, good source id, but low statistics



Probably the most exciting result in the search for Dark matter: Fermi LAT 135 GeV line



Bringmann et al. , Weniger, many Fermi LAT presentations

However the significance of the line detection is not enough to state it with 100% confidence, and it is unlikely that Fermi LAT will be able to claim it as a globally significant result by the end of the mission

New experiments are needed !

γ-ray lines in diffuse radiation : Perspectives for GAMMA-400

Back-on-envelope estimate:

Sensitivity to the γ-ray line (flux) in the diffuse radiation can be expressed in simplified form as: $I_\gamma = \frac{n_\sigma}{0.68}\sqrt{\frac{2F_{bck}\eta E_\gamma}{GT}}$

where n is a number of σ , F_{bck} is a (diffuse) background, ηEγ is an energy bin width, which depends on η (energy resolution), G is a geometric factor, T is an observation time

Comparison of Fermi LAT and GAMMA-400 sensitivity:

- **ηEγ for GAMMA-400 is 10X less than that for Fermi LAT at E>100 GeV,**
- **G for GAMMA-400 is ~ 0.5 of that for Fermi LAT,**
- **the sensitivity for GAMMA-400 for the same observation time is expected to be ~ 2 better than for Fermi LAT.**

γ-ray line from source : Perspectives for GAMMA-400

Assumption: the line is a δ-function in energy spectrrum

Confidence estimate: Confidence of the line detection can be taken similarly to the confidence in detection of point source (probability for the background to fluctuate to create a "feature")

$$C = \frac{N_{sig}}{\sqrt{N_{bkg}}}$$

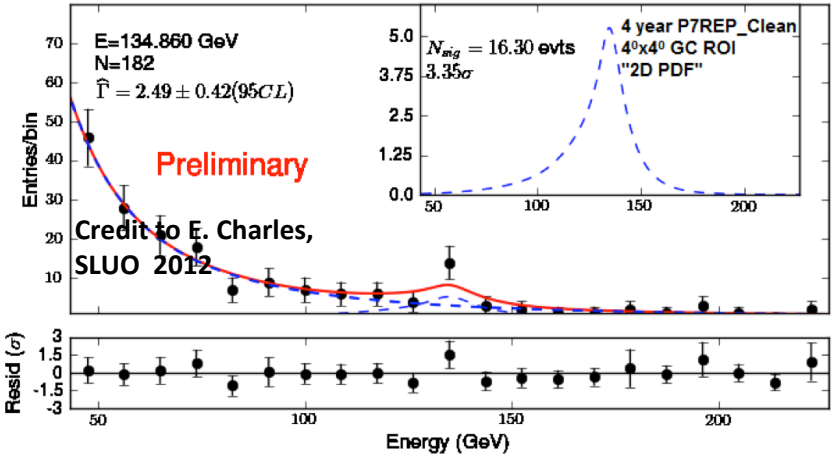
where N_{sig} is a number of events from the "line" (source), and N_{bkg} is a number of background (diffuse) events

With 10X better PSF for Gamma-400:

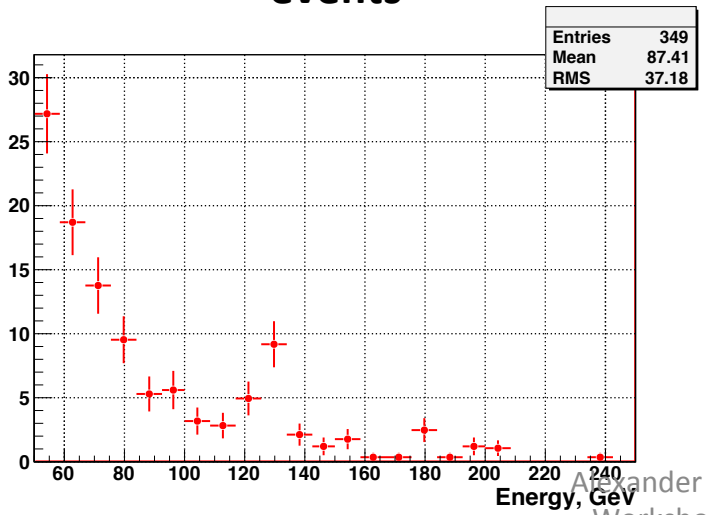
- N_{bkg} can be 100X less,
- detection confidence C will be ~5X larger, assuming twice less events from the "line" N_{sig} detected (due to smaller A_{eff})
- All this works only for the point source!

Illustration with “135 GeV line” Toy model simulation

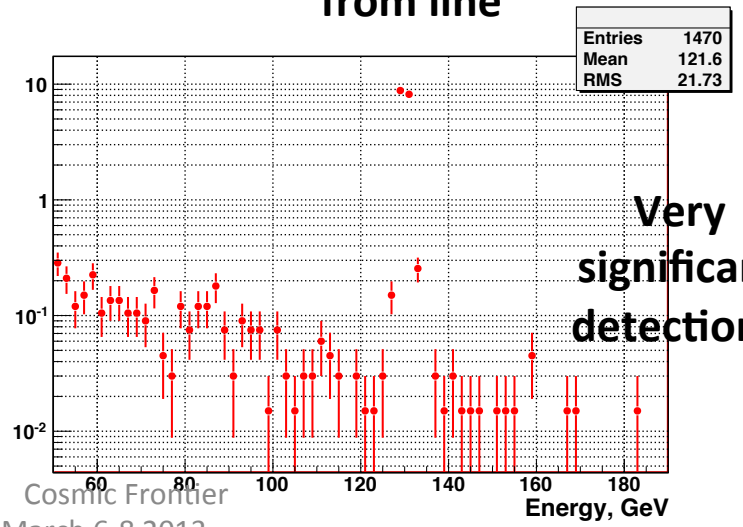
Only for the point source. Less advantage for the extended source



LAT-like instrument, 300 events



Gamma-400, 10X better dE/E, 10X better PSF (100X less background), same # of events from line



Very significant detection !

Galactic Center

- **Expected to be the strongest source of γ-rays from DM annihilation. "EGRET GeV excess" has been in the center of DM discussion for years, until it was closed by Fermi LAT results**
- **Intense background from unresolved sources remains the main problem, assuming that the part of background created by CR interactions with the matter, is much better known and can be accounted for**
- **Potential perspectives for GAMMA-400: having >10 times better angular resolution at high energy, faint sources in dense GC area can be localized and their radiation can be removed as a background, and better model of diffuse radiation can be built. Concern: smaller effective area can make this analysis more difficult and not efficient**

Clumps : Perspectives for GAMMA-400

Features to search for:

- Hard (Not power-law) energy spectrum
- Extended spatial dimensions
- Lack of counterparts in other wavelengths

Approach:

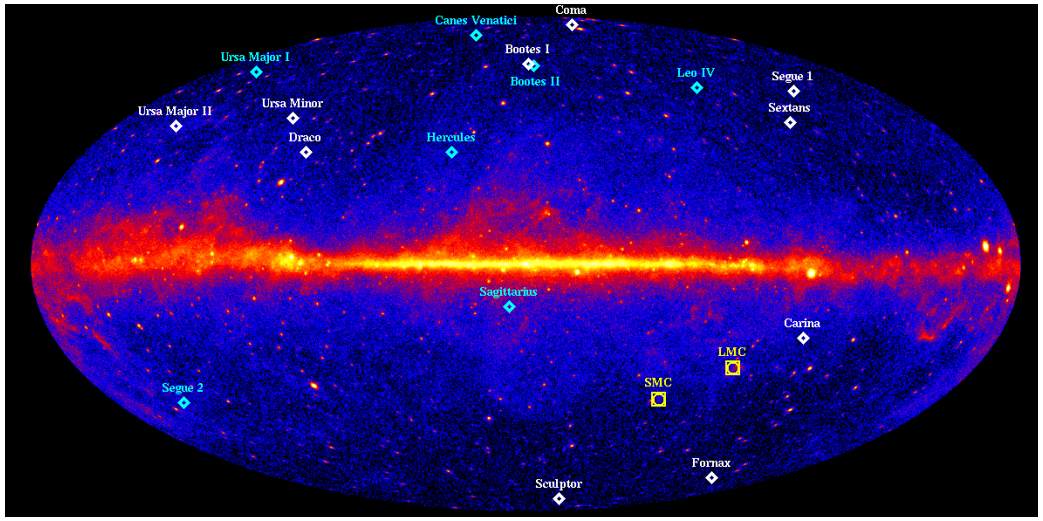
- Check among available by that time non-ID Fermi LAT and GAMMA-400 (if found) *γ*-sources to meet the above criteria

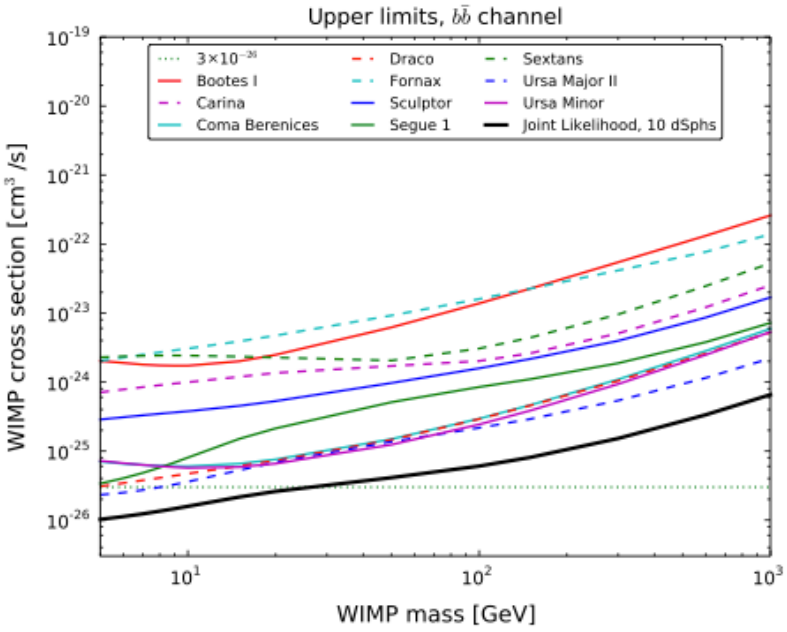
Perspectives:

- Better energy resolution will allow to better distinguish between power-law "normal source" and hard DM spectra, potentially increasing the number of satellite candidates
- Better angular resolution will allow to better distinguish between point and extended sources, also potentially increasing the number of satellite candidates
- Larger number of available by that time non-ID Fermi LAT sources shall also increase the number of satellite candidates

Dwarf Spheroidal Galaxies: prominent DM candidates

- Search for γ–ray emission from Dwarf Spheroidal Galaxies (satellite galaxies) with large J-factor (line-of-sight integral of the squared DM density)
- Fermi LAT applied a joint likelihood analysis to 10 satellite galaxies: no dark matter signal was detected. Upper limit for $\langle \sigma v \rangle$ is set to ~10^{-26} cm^3 s^{-1} at 5 GeV and 5 x 10^{-23} cm^3 s^{-1} at 1 TeV (Ackermann et al. PRL 107, 241302, 2011)





Dwarf Spheroidal Galaxies: Perspectives for GAMMA-400

Joint likelihood (for 10 dSphs) of agreement between observed *γ*-radiation and that predicted by DM model:

Energy-binned *γ*-ray data; should be better for Gamma-400

$$L(D|\mathbf{p}_w, \{\mathbf{p}\}_i) = \prod_i L_i^{\mathrm{LAT}}(D|\mathbf{p}_w, \mathbf{p}_i) \times \frac{1}{\ln(10) J_i \sqrt{2\pi}\sigma_i} e^{-[\log_{10}(J_i) - \overline{\log_{10}(J_i)}]^2/2\sigma_i^2},$$

Binned Poisson likelihood fully accounting of the PSF (E); should be better for Gamma-400

Improved dE/E and PSF for GAMMA-400 should provide better sensitivity for this analysis

CALET:

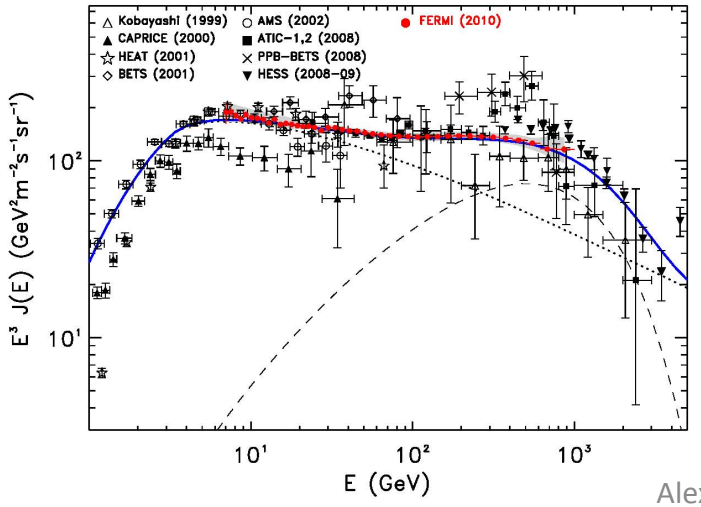
It is going to provide the best data on high energy electrons

What can be done here for dark matter search?

Cosmic rays: Electrons and Positrons

Fermi LAT electron spectrum cannot be explained within conventional single-component model,

- **but introduction of an additional component of the CRE flux with hard spectrum can resolve the problem,**
- **This component can be astrophysical (many different scenarios have been considered) or "exotic", such as dark matter clump. Complementary to other observations (but in what meaning of "complementary"?)**



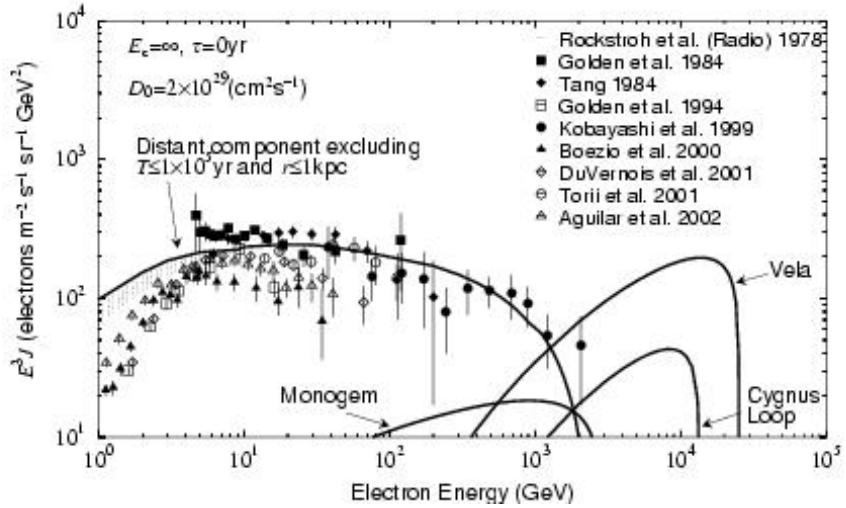
CALET: with its superior energy range and resolution can provide critical information on the spectral structure

Big luck: δ-function-like "leptonic" feature. Can it be?

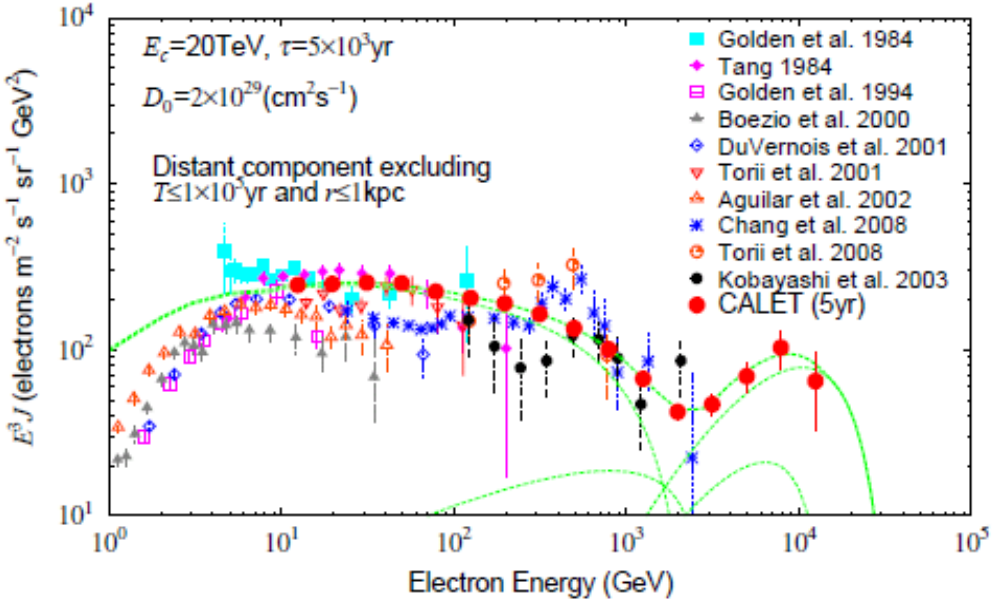
A bit of classics : Observation in the trans-TeV region

Kobayashi et al. ApJ (2004) :

Ec=∞、ΔT=0 yr, Do=2x10^{29} cm^2/s



What CALET can get for 5 years:



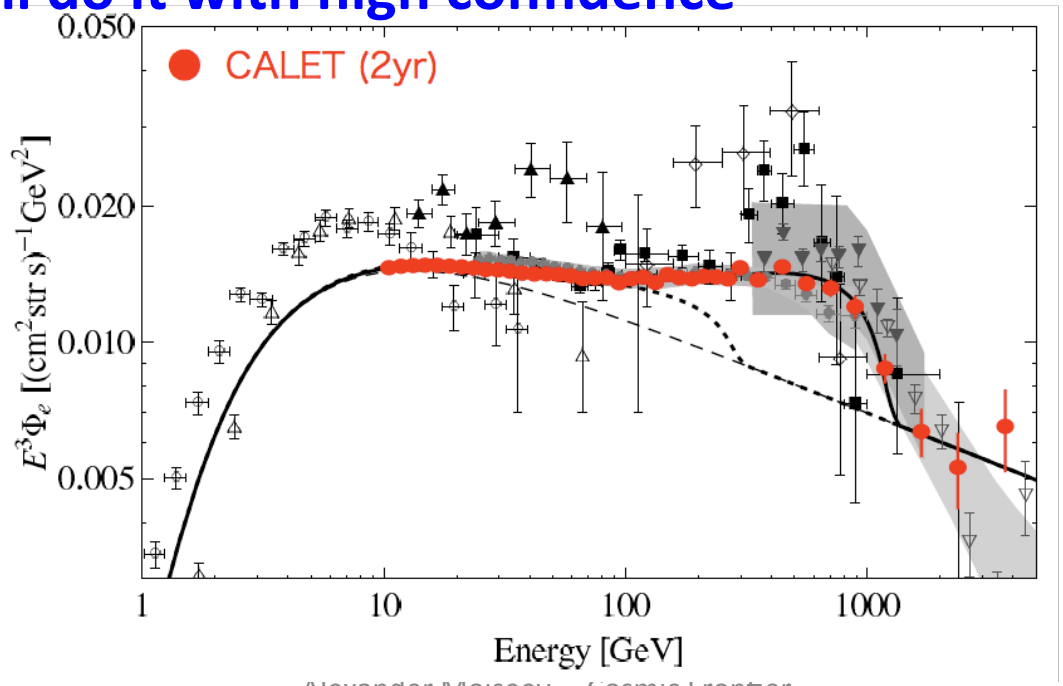
If there are spectral features (like reported by ATIC), CALET will find them with high confidence

Electron spectrum

Very important (however likely not a dark matter issue):

reported by H.E.S.S. sharp spectral break above 1 TeV

- **We hope that Fermi LAT with Pass8 analysis will be able to prove/disprove it**
- **CALET will do it with high confidence**



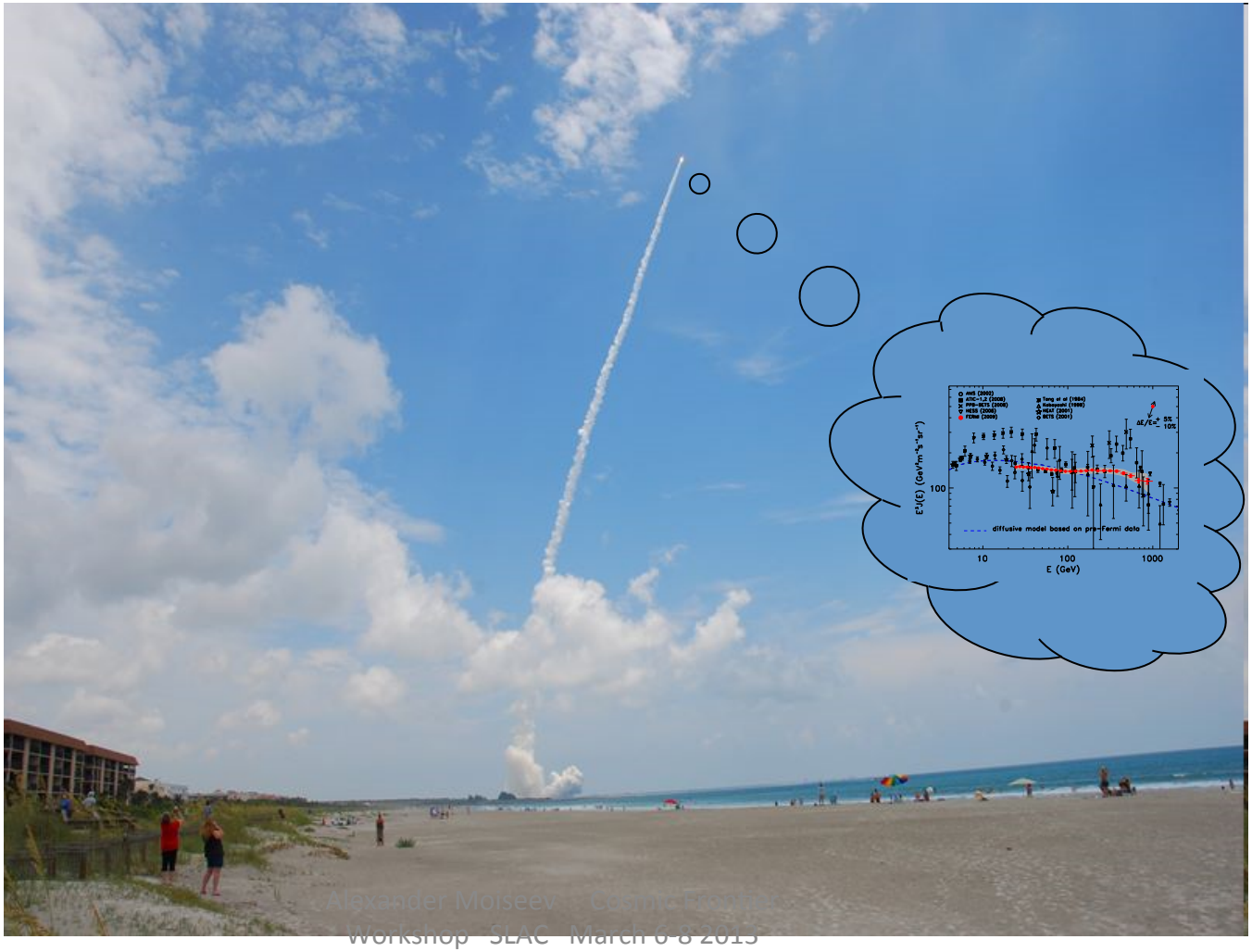
SUMMARY

- **Two new powerful facilities are joining the big hunt**
  - ✓ **GAMMA-400: excellent angular and energy resolution above 10 GeV - Line(s), Galactic center, …**
  - ✓ **CALET: the most accurate and statistically significant measurement of the electron spectrum – nearby sources (astrophysical or exotic)**

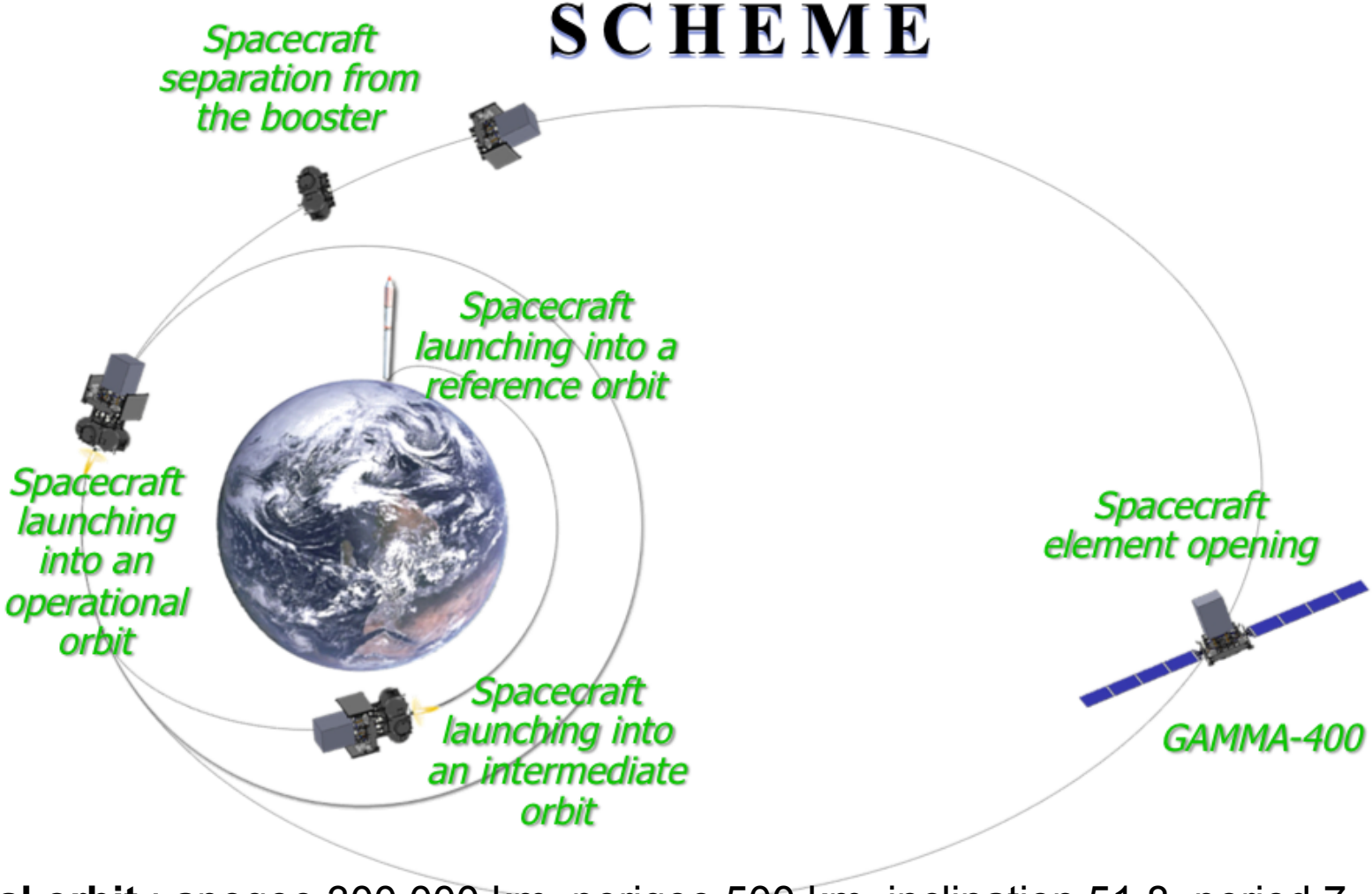
We need inputs from theorists on how to tune the instruments and observations (it is still possible) to catch a big fish!

STAY TUNE!

THANK YOU !



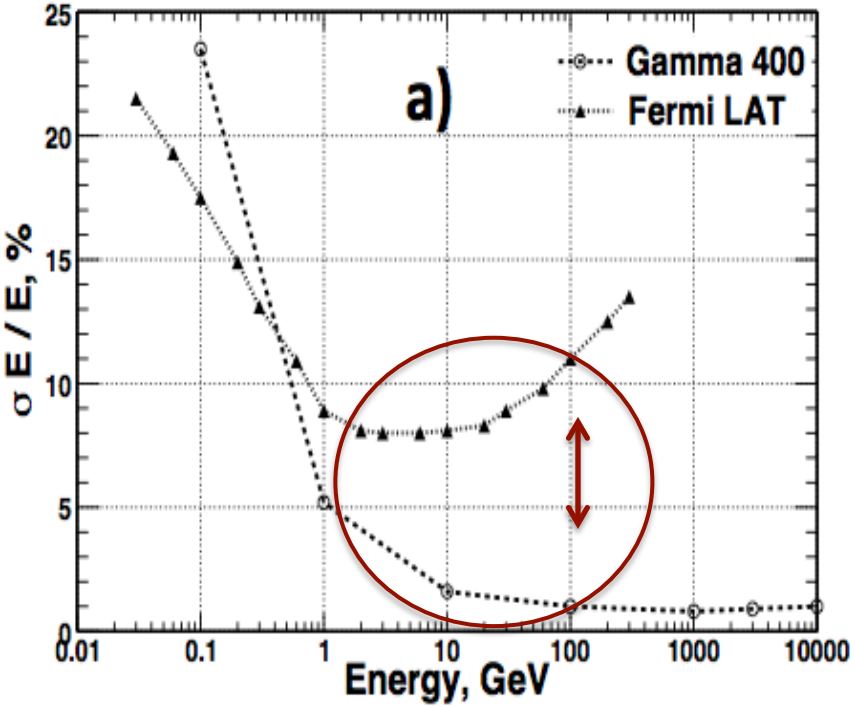
GAMMA-400 LAUNCHING SCHEME



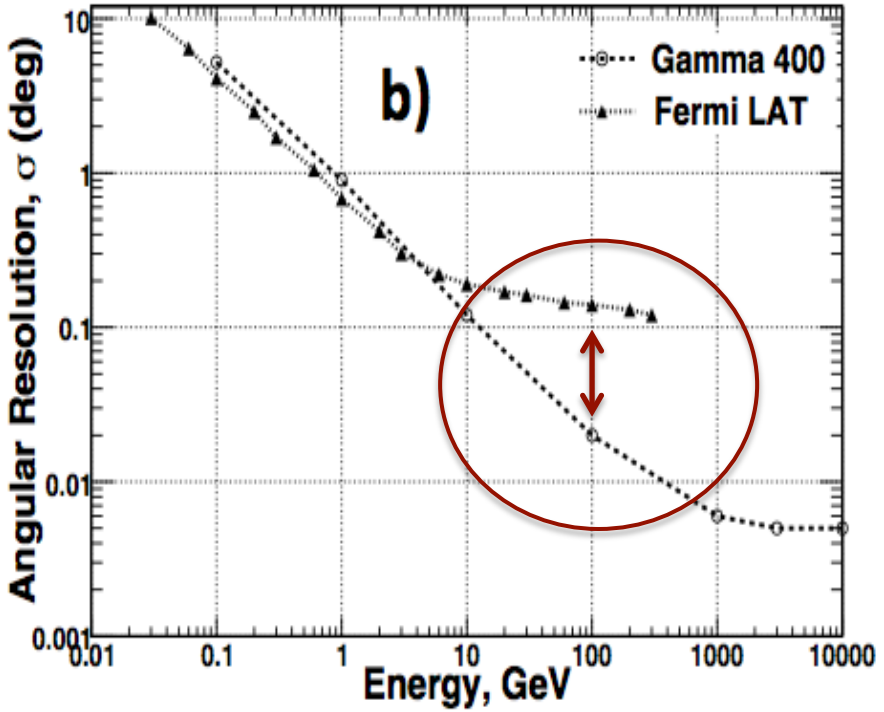
Initial orbit : apogee 300,000 km, perigee 500 km, inclination 51.8, period 7 days**. After ~ 230 days** the orbit will change to ~ circular with radius 150,000 km

GAMMA-400 Key Performance

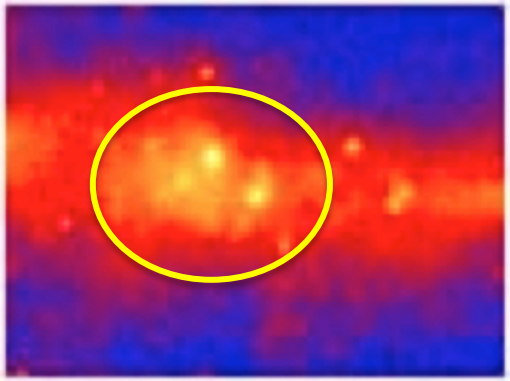
Energy Resolution



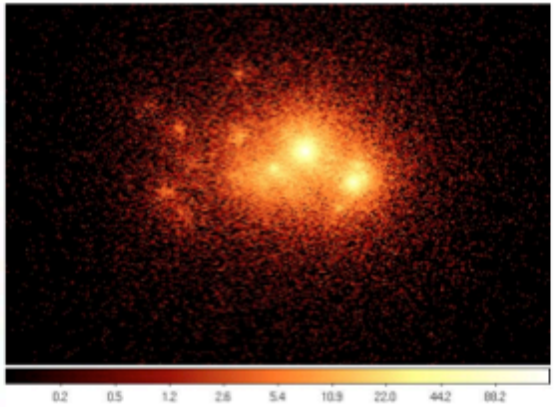
Angular Resolution



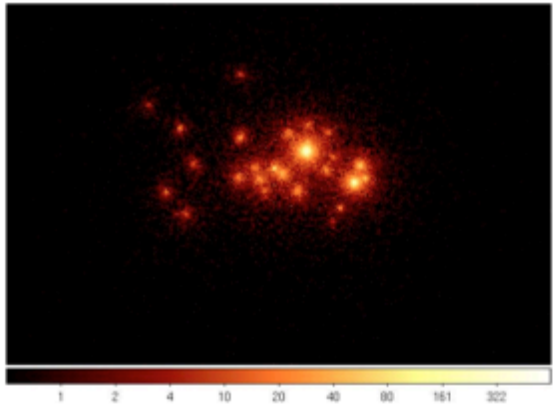
Cygnus region (above 30 MeV) as seen by Fermi LAT and simulated for Gamma-400



Fermi LAT 2-year flight data



Fermi LAT 2-year simulated data



Gamma-400 2-year simulated data